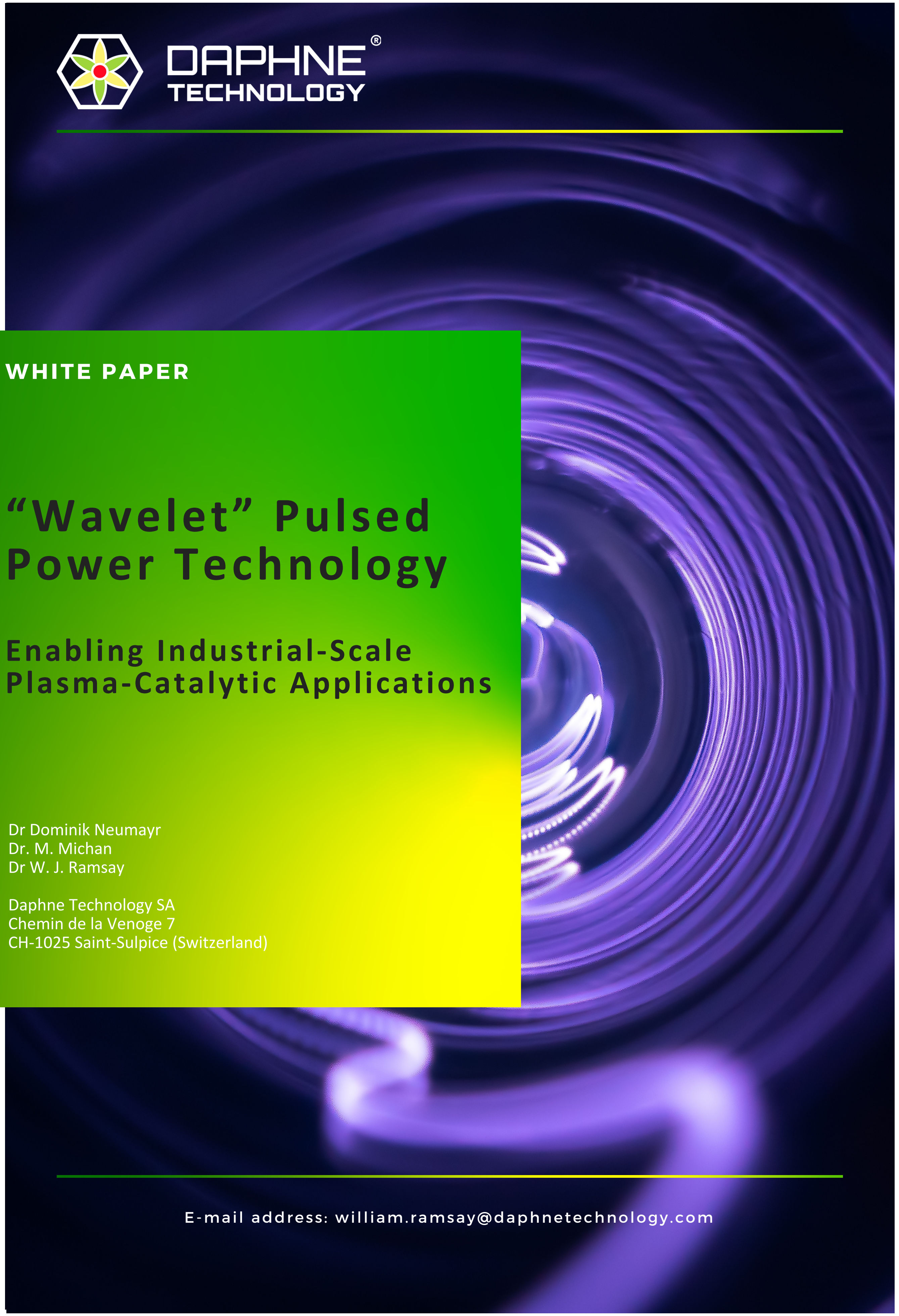

WHITE PAPER

“Wavelet” Pulsed Power Technology

Enabling Industrial-Scale Plasma-Catalytic Applications

Dr Dominik Neumayr
Dr. M. Michan
Dr W. J. Ramsay

Daphne Technology SA
Chemin de la Venoge 7
CH-1025 Saint-Sulpice (Switzerland)

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E-mail address: william.ramsay@daphnetechnology.com

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1. Introduction

Daphne Technology is developing SlipPure™, a long-awaited solution to remove methane (CH_4) emissions from post-combustion exhaust streams of large engines, encountered in industries such as maritime, oil & gas, and other hard to decarbonize industries. Methane is a very stable molecule and proposed abatement solutions mostly rely on MOC (Methane Oxidation Catalysts) which require a comparably high activation temperature, also referred to as light-off temperature, in excess of 450°C to abate methane. This high light off temperature is attained by changing the engine timing, using heaters or afterburner devices. This results in degraded efficiency. In order to drastically lower the activation temperature and improve methane conversion to meet market demands, Daphne Technology is combining Non-Thermal Plasma (NTP) technology together with a tailored catalytic material in a novel Plasma-Catalytic Converter (PCC).

The basic structure of a single reactor cell is depicted in Figure 1, showing a catalyst substrate inserted in a quartz tube with inner and outer electrode in a cylindrical configuration. By applying a high-frequency AC voltage with high amplitude on 10s of kV between the electrodes, NTP is generated in the exhaust gas passing through the channels of the catalyst improving the conversion of methane to CO_2 (with CO as an intermediary species) due to a synergistic interaction of the catalytic material with the plasma. Similar to a battery pack with individual battery cells, a large number of plasma-catalytic cells are packaged together to form an industrial-scale PCC capable of processing several kg/s of exhaust mass flow.

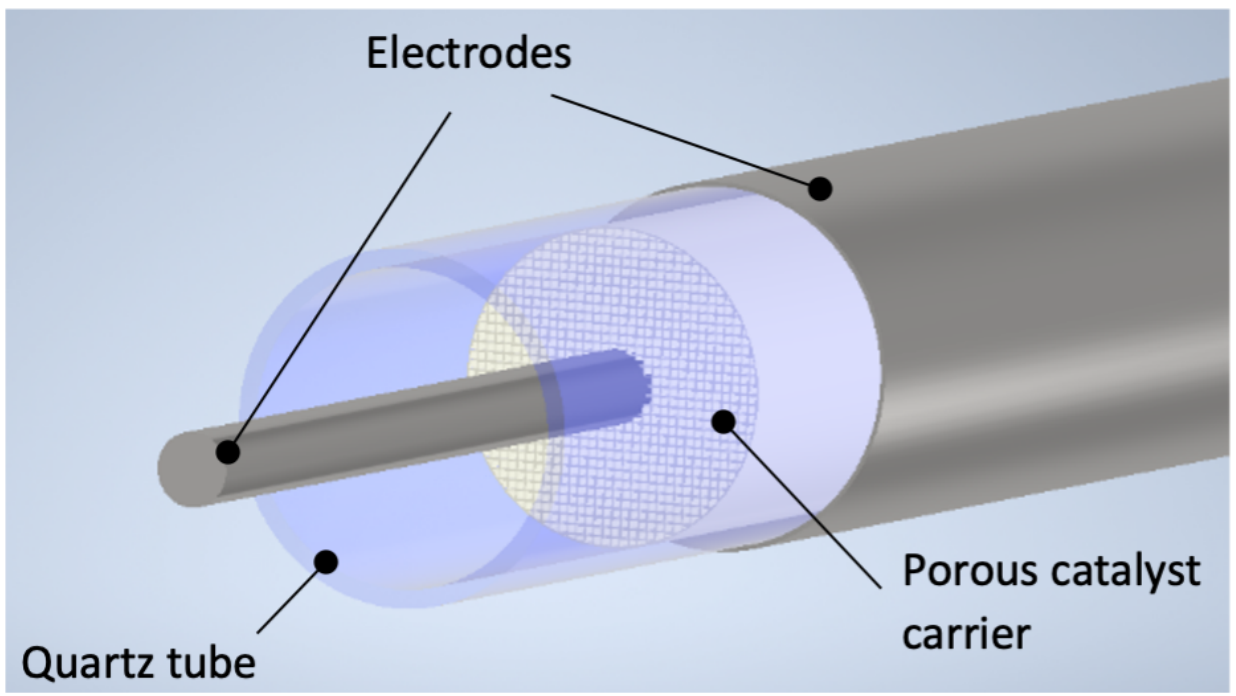

Fig. 1.
Simplified illustration of a plasma-catalytic reactor cell

2. Challenges at Industrial Scale

In a first approximation, the PCC can be represented electrically as a capacitor, two electrodes with a dielectric material in between representing the reactive power of the PCC, and an equivalent series resistance (ESR) representing the active/real power absorbed by the PCC when the plasma is present [1]. Since the reactive power is much larger (~10x), the power factor of the PCC is very low (< 0.2), typically resulting in low efficiency of the power supply.

In order to initiate the formation of the NTP, a high voltage amplitude in the range of 10s of kV is needed. Furthermore, as described in literature [2, 3] and confirmed by numerous experiments in Daphne’s R&D laboratory, minimizing rise-time and pulse-width of the applied voltage pulse results in better methane reduction per unit of applied electrical energy. The low power-factor nature of the load in combination with the pulse-shape requirements, limits the achievable power transfer capability with commercially available pulsed-power equipment available from other industrial plasma applications.

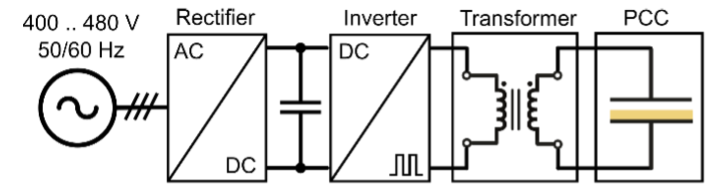

Fig. 2.
Simplified schematic of Daphne’s wavelet pulse power (WPP) supply.

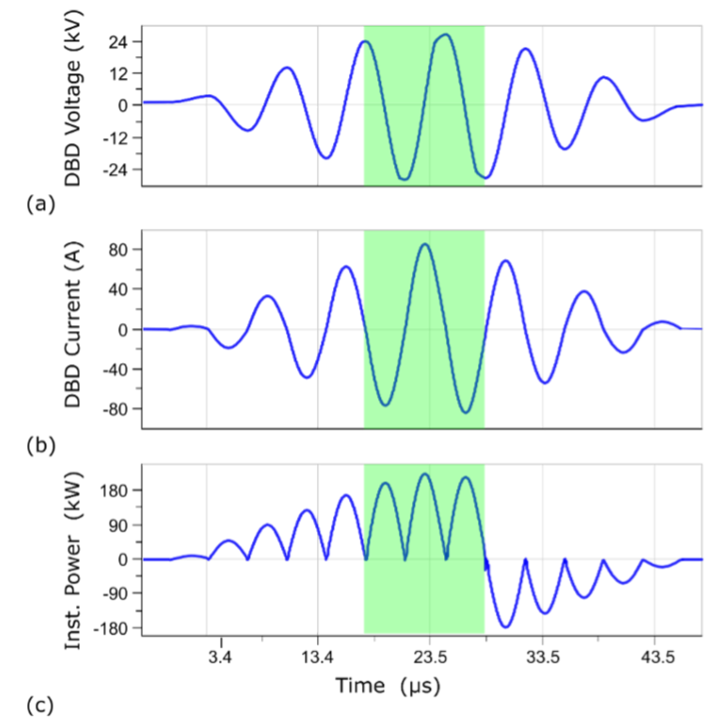

Fig. 3.
Characteristic waveforms of the “Wavelet” type pulse power proposed by Daphne Technology.

3. Wavelet Pulse Power (WPP)

A novel concept [4], proposed and implemented by Daphne Technology, to drive industrial-scale PCCs and to overcome the aforementioned challenges, is described in the following. The notation “Wavelet” was chosen as the resulting voltage/current waveforms applied to the PCC, a sinusoid with increasing and decreasing amplitude as shown in Figure 3 (a-b), resemble the wavelet function used in mathematics. The WPP converter system, as represented by a simplified schematic in Figure 2, is based on the combination of the following concepts:

1) Reactive Power Compensation:
The capacitance of the plasma-catalytic converter can be compensated with the leakage inductance provided by the transformer of the power supply forming a so-called resonant tank. When operating close to the resonance frequency, the inverter operates with minimal switching

losses and only supplies active power during the plasma-cycle, when the plasma is present (light-green shaded area in Figure 3), enabling operation at very high excitation frequencies which results in the desired small rise-times and pulse-widths. Furthermore, the energy stored in the resonant tank is recovered after every plasma-cycle as can be seen from the negative instantaneous power as shown in Figure 3 c), measured at the output of the inverter.

2) Leveraging the Resonance Phenomena:
The 3-phase low-voltage distribution network present in industry or on-board of ships has a voltage amplitude between 400V .. 480V. In order to reach plasma ignition voltage levels of 10s of kV, the power supply needs to increase the voltage amplitude substantially. When the resonant tank is excited close to the resonance frequency, a very high voltage is building up across the reactor without the need for a transformer with high step-up ratio. This has the advantage to achieve the required plasma ignition voltage level while keeping the current stress on the low-voltage side of the transformer and inverter comparably low, resulting in better conversion efficiency and a reduced footprint of the power supply.

3) Robustness and Simplicity of Control:
Resonance power conversion is a mature and widely adopted technology with excellent efficiency but more complex to implement control. In conventional applications, typically phase-control is employed to regulate the output voltage and/or the active power flow. However, correctly determining the phase-shift at hundreds of kHz excitation frequency becomes very challenging. Furthermore, the equivalent capacitance of the PCC is not constant but increases when the plasma is present.

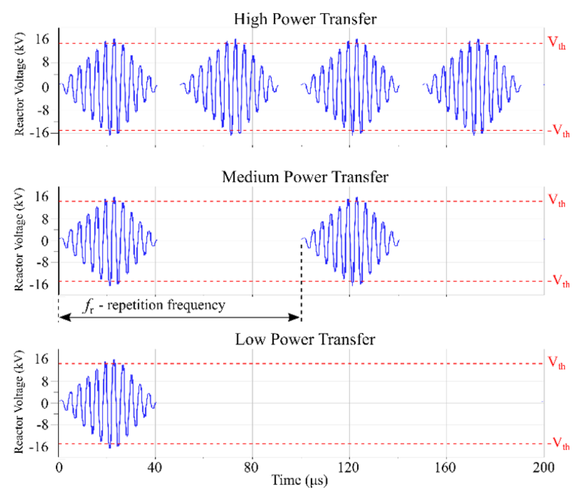

Fig. 4.
Adjusting the active power transfer by means of varying the wavelet repetition rate.

For this reason, a simple and robust duty-cycle control is preferred, whereby the operating frequency is chosen to be close to resonance at the beginning of the cycle (when the voltage is below ignition threshold) to benefit from maximal voltage gain. Shortly after reaching the plasma ignition voltage level, the excitation is stopped and energy stored in the resonant tank is recovered and stored in the DC-link buffer capacitor (capacitor between rectifier and inverter as shown in in Figure 2) by means of the free-wheeling diodes present in the inverter. For every applied Wavelet, a certain amount of electrical energy is being absorbed by the PCC (The exact amount depends on various parameter, such as DC link voltage, operating frequency, width of the wavelet etc.). By varying the rate of repetition, i.e. how frequently Wavelets are being applied to the PCC, the average active power absorbed by the PCC can be adjusted with high accuracy, adopting to variations in the exhaust mass flow and CH_4 concentration levels present at different engine operation points.

4. Conclusion

The white paper introduces SlipPureTM, a Plasma-Catalytic Converter (PCC) technology developed by Daphne Technology to reduce post-combustion methane emissions from large gas engines. By combining Non-Thermal Plasma (NTP) with tailored catalytic materials, the PCC offers a solution for industries such as maritime and oil & gas to reduce their greenhouse gas emissions. To address the challenges of low power factor and demanding pulse-shape requirements, the paper presents Wavelet Pulse Power (WPP), a novel concept for driving industrial-scale PCCs. WPP utilizes reactive power compensation, leverages resonance phenomena, and implements a robust duty-cycle control to optimize power flow and improve overall conversion efficiency while achieving high operating frequencies as required by the PCC. This innovative approach enables precise adjustment of active power absorption by the PCC, accommodating variations in exhaust mass flow and methane concentration levels.

5. References

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